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The Status of the IEEE Standard on Transitions, Pulses, and Related Waveforms

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Abstract

In recent years, the IEEE has been revising the now expired IEEE standards on pulse techniques and definitions. This revision includes adding and deleting definitions, clarifying existing definitions, providing examples of different waveform types, updating text to reflect electronic computation methods, and incorporating algorithms for computing waveform parameters.

I. Introduction

The Subcommittee on Pulse Techniques (SCOPT) of the IEEE Technical Committee 10 (TC-10, Waveform Measurement and Analysis) has, over the last few years, been in the process of writing a new standard on terms, definitions, and algorithms for describing and computing waveform parameters that is based on two expired IEEE standards, IEEE STD-181-1977, Standard on Pulse Measurement and Analysis by Object Techniques[1], and IEEE-STD-194-1977, Standard Pulse Terms and Definitions[2]. These expired IEEE standards were adopted in 1987 by the International Electrotechnical Commission and are the IEC 60496-2, Pulse Techniques and Apparatus, Part 2: Pulse measurement and analysis, general considerations, and IEC 60469-1, Pulse Techniques and Apparatus, Part 1: Pulse terms and definitions.

As stated in the proposed standard (still under development), the purpose of the standard "is to facilitate accurate and precise communication concerning parameters of transition, pulse, and related waveforms and the techniques and procedures for measuring them." Because of the broad applicability of electrical pulse technology in the electronics industries (such as computer, telecommunication, and test instrumentation industries), the development of unambiguous definitions for pulse terms and the presentation of methods and/or algorithms for their calculation is important for communication between manufacturers and consumers within the electronics industry. The availability of standard terms, definitions, and methods for their computation helps improve the quality of products and helps the consumer better compare the performance of different products.

Improvements to digital waveform recorders have facilitated the capture, sharing, and processing of waveforms. Frequently these waveform recorders have the ability to process the waveform internally and provide pulse parameters. This process is done automatically and without operator intervention. Consequently, a standard is needed to ensure that the definitions and methods of computation for pulse parameters are consistent.

The SCOPT is comprised of an international group of electronics engineers and physicists with representatives from national metrology laboratories, national science laboratories, the test instrumentation industry, and academia. The SCOPT meets two to three times a year to discuss terms describing waveform parameters, the definitions of these terms and, if appropriate, algorithms for calculating values for those parameters. Recently, the SCOPT has completed a major revision of the proposed standard and is expected to ballot in mid-year of 2002. Interested knowledgeable parties are welcome and encouraged to participate in the balloting process (please contact the IEEE TC-10 chairman).

The three major areas the SCOPT addressed to improve the proposed standard relative to the expired IEEE standards

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are: definitions, algorithms, and examples. How the SCOPT has addressed these topics will be discussed in this document. The SCOPT will also combine the material and concepts presented in the two expired standards into one standard.

II. Definitions

The proposed IEEE standard contains definitions for approximately 100 terms commonly used to describe waveform parameters. Many of the terms that were in the 1977 IEEE standards have been deleted or deprecated. Deprecated terms were kept in the proposed standard to provide continuity between this proposed standard and the IEC documents. The terms are deprecated because they cannot be defined unambiguously or precisely.

The first major distinction between the definitions in the expired and proposed standard is to clearly differentiate between a pulse and its waveform, the latter being a measured representation of a physical event. All algorithms are defined for waveform parameters and the definitions are written accordingly. Also, step-like, pulse, and impulse-like waveforms are described in the proposed standard. Step-like waveforms are waveforms where the initial and final states of the waveform are different and there is only one transition. These are the signals that are typically output by high-speed electrical pulse generators and frequently used in sampler calibration. A pulse waveform is a compound waveform that is described as being the summation of two step-like waveforms having amplitudes of equal magnitude but opposite sign and with one delayed relative to the other. An impulse-like waveform is a waveform that starts at some level, achieves a peak value, and then immediately returns to the starting level.

II.1 States

In the expired standards, the word "line" was used to describe the value corresponding to the nominally constant-valued regions of a waveform. Terms such as "topline" and "baseline" (or "bottom line") were used. "Line" is a graphical

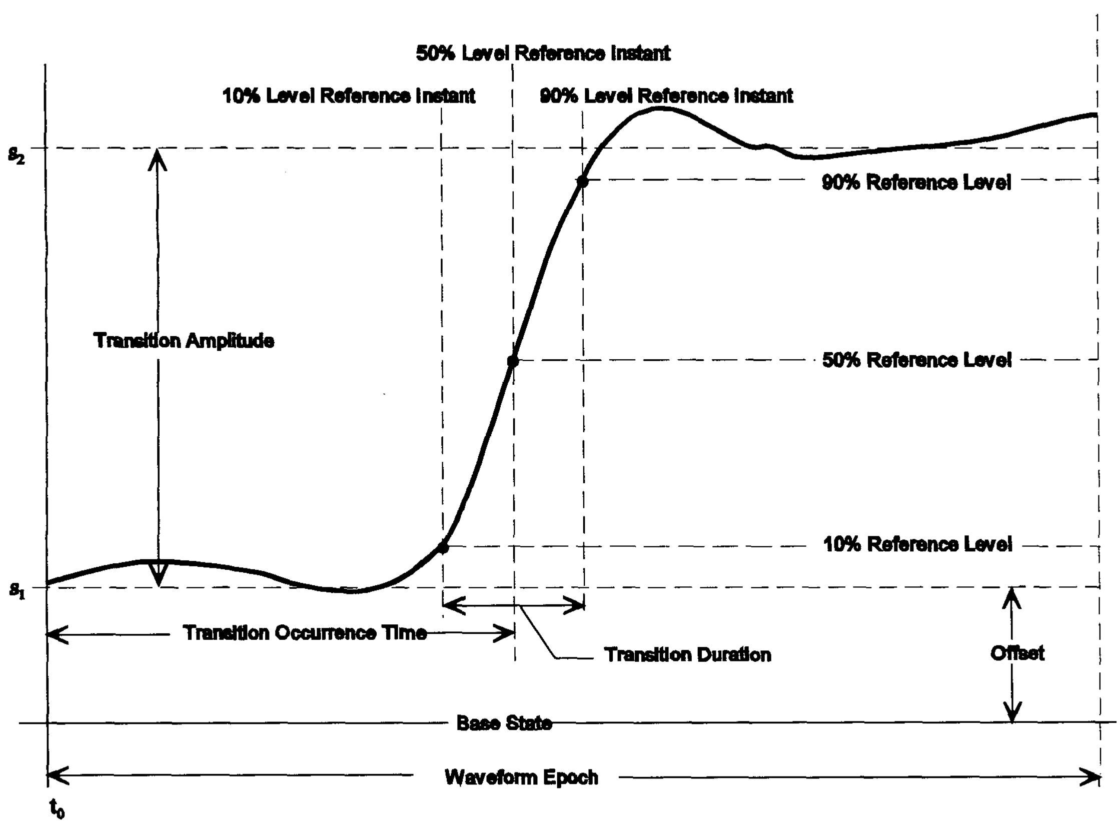

Figure 1. Step-like waveform exhibiting a positive-going transition from state s_1 to state s_2.

description and not an appropriate term for electronic computation of waveform parameters or for describing the output of a physical device. The term presented in the proposed standard is "state." State is also consistent with the description of constant-valued currents or voltages from the output of actual electronic devices. States are numbered starting at the most negative and ending at the most positive, and are designated by $s_1, s_2, ..., s_n$, where s_n is the most positive state and s_1 is the most negative state for an n-state waveform. For example, the waveform shown in fig. 1 is a two-state waveform. Each state has an associated level which describes the value (number with units) for that state. For example, the two-state waveform in fig. 1 can have s_1 = 0. V and s_2 = 0.25 V. Associated with a state are upper and lower boundaries, and a waveform is said to be in this state if its values are within these boundaries for a user specified duration. The difference between the upper boundary and lower boundaries can be different for each state.

II.2 Reference Levels and Instants

Reference amplitude values were called "reference lines" in the expired standards, such as the "10 % reference line." Again this is a graphical representation and not representative of a physical device. The proposed standard uses the term "percent reference level" and this value is referenced to the amplitude of the waveform (the same way "reference line" was referenced to the waveform amplitude). Similarly, it was necessary to redefine the instants that the waveform crosses the reference levels. The expired standard used the term "point," which again is a graphical representation. The proposed standard uses "reference level instant." This usage unambiguously ties the reference level to its occurrence.

II.3 Transition Duration

Some very commonly-used terms that are ambiguous in their definition are fall time, rise time, overshoot, and undershoot. For example, rise time is used to describe the duration of a positive-pulse waveform for the transition going from the waveform's low state to its high state (see fig. 1). However, rise time is also commonly used to describe the duration for a negative-pulse waveform for the transition going from the waveform's high state to its low state. This duration is more commonly called its fall time. To eliminate this confusion, rise time and fall time are not used. Instead, the term transition duration is used. Transition duration is dependent on the amplitude of the waveform and the slope of the transition. To differentiate between the transition duration for a negative-going or positive-going transition, the adjectives "positive-going" and "negative-going" are used. So, in the first example given, we are describing the transition duration of positive-going transition of the waveform. If there is more than one transition, the proposed standard requires parsing the waveform epoch into m waveform subepochs, where m is the number of transitions in the waveform.

II.4 State Occurrences

The definition of a pulse waveform requires that the pulse waveform meet certain requirements. One of these requirements is that the pulse waveform attains certain states and another is that the waveform remains in each of those states for a certain duration. State occurrence refers to the instants for which the waveform enters a given state. For example, if the waveform values are approaching a state from more negative values than that of the state level, once the waveform crosses the lower state boundary, the waveform is said to be in that state. Once the waveform exits that state by either taking on values more negative than the lower state boundary or more positive than the upper state boundary, the waveform is no longer in that state. The proposed standard has a definition for "minimum duration for state occurrence." This is a user defined duration for which durations of state occurrences less than this user-specified value are not considered state occurrences. This term is useful for differentiating runts and glitches from rectangular pulses in a waveform.

II.5 Overshoot and Undershoot

As mentioned, overshoot and undershoot are ambiguous terms. Undershoot is often called preshoot, which is describing an amplitude in terms of time. The proposed standard eliminates this ambiguity by specifying whether the overshoot and undershoot occur before or after a transition. Accordingly, there are four possible terms, pre-transition overshoot, pre-transition undershoot, post-transition overshoot, and post-transition undershoot. Overshoot and undershoot have historically been the most often quoted waveform aberration. However, other waveform aberrations are also becoming important, such as settling error and settling time, and there is a need to define regions over which the aberrations may occur. For instance, waveform recorders frequently specify a maximum settling error within different time intervals from a reference instant. Unless otherwise restricted, a post-transition overshoot may be computed as the maximum error. To be consistent with the present use of the terms "overshoot" and "undershoot," the waveform near the transition is separated into pre-transition and post-transition intervals. The duration of these intervals equals three times the transition duration, unless otherwise indicated. For the pre-transition aberration region, the interval starts at the 10 % reference level instant and extends toward the initial instant (first time of waveform epoch). For the post-transition aberration region, the interval starts at the 90 % reference level instant and extends toward the final instant (last time of waveform epoch).

II.6 Other Terms

Many other terms and their definitions were added for completeness, such as terms for different types of jitter, impulse-like waveforms, and for different types of features in a waveform (glitch, runt, spike,etc.). The definitions of several other terms that are in the IEC documents (and in the expired IEEE standards) have been rewritten to be more precise and, hopefully, less ambiguous than what is presented in the expired standards.

III. Algorithms

Algorithms have been written in the proposed standard to compute most of the defined waveform parameters.

III.1 State Levels

The expired standards only described methods to compute state levels, and these methods were based on graphical histograms. The proposed standard also describes histogram methods to determine the state levels in a waveform. In some instances, pseudo-code algorithms are provided for computing histograms based on iterative methods. These iterative methods are based on determining the number of bins that gives accurate estimates of the state levels. (The full amplitude range of the waveform is partitioned into a series of non-ovelapping amplitude regions or bins.) The iterative histogram methods use some pre-determined criterion of the histogram or waveform to determine the preferred number of bins. It is not necessary that the histogram have equal-sized bins.

Once the histogram is determined, the user chooses whether the mean, mode, or median of the histogram is used to determine the state levels. The proposed standard provides steps for computing the state levels for each of these three histogram-based methods.

Other methods are also allowed in the proposed standard for determining state level, such as using peak amplitudes, the amplitude values at the initial and final instants of the waveform, user-defined values, static levels, and multiple waveform epochs. The first four methods rely on knowledge about the pulse and its corresponding waveform or on the devices used to generate the pulse. Multiple waveform epochs may be used in the case when a short epoch is necessary to determine transition duration but the waveform does not attain a state level. In this case, a longer epoch is used to determine the state levels.

III.2 Algorithm Examples

All waveform parameters are based on having values for the low and high states. As mentioned before, any m-state waveform can be decomposed (or parsed) into a set of n two-state waveforms where n is the number of transitions in the waveform. Once the two-state waveforms are obtained, their state levels can be determined using histogram or other methods. The proposed standard provides step-by-step procedures for computing most of the defined waveform parameters.

The first waveform parameter that is necessary in analyzing a waveform or determining its waveform parameters is waveform amplitude. Waveform amplitude is the difference between the levels of s_2 and s_1. The algorithm used for computing waveform amplitude is:

"5.3.1. Algorithm for Calculating Waveform Amplitude

(1) Determine s_1 and s_2 using a method described in Section 5.2.

(2) The waveform amplitude, A, is the difference between *level(s2)* and *level(s1)*.

(2.1) For positive-going transitions, A is given by:

$$A = level(s_2) - level(s_1).$$

(2.2) For negative-going transitions, A is given by:

$$A = level(s_1) - level(s_2)."$$

Section 5.2 describes the methods for computing state levels; these methods are the histogram or other methods described earlier. The reference levels can then be computed from the waveform amplitude. From these reference levels, the corresponding reference level instants are computed. Most other waveform parameters can be computed from the reference levels and the reference level instants.

The algorithm section is written in a hierarchical manner, describing the algorithms for the most basic waveform parameters first and then using these algorithms to develop more advanced waveform parameter algorithms. For example, the algorithm for the waveform parameter transition duration is:

"5.3.4 Algorithm for Calculating Transition Duration Between Reference Levels $x_{1\%}$ and $x_{2\%}$.

(1) Determine s_1 and s_2 using a method described in Section 5.2.

(2) Calculate the reference level instant, $t_{x1\%}$, for the $y_{x1\%}$ reference level in accordance with Section 5.3.3 that is nearest to the 50 % reference level instant, unless otherwise specified.

(3) Calculate the reference level instant, $t_{x2\%}$, for the $y_{x2\%}$ reference level in accordance with Section 5.3.3 that is nearest to the 50 % reference level instant, unless otherwise specified.

(4). Calculate the transition duration, $t_{x1\%-x2\%}$:

$$t_{x1\%-x2\%} = \left| t_{x1\%} - t_{x2\%} \right|."$$

Section 5.3.3 in this algorithm contains the algorithm for calculating reference level instants, which in turn references the algorithm for calculating reference levels, and this algorithm references Section 5.3.1, which was described earlier.

III.3 Other algorithms

The proposed standard includes algorithms for other two-state single-transition waveform parameters, such as, undershoot, overshoot, waveform aberration (outside of the pre-transition and post-transition aberration regions), and transition settling duration and error. For two-state, n-transition waveforms, the proposed standard contains algorithms for pulse duration, waveform period, pulse separation, and duty factor. The proposed standard provides two algorithms for impulse- like waveforms, they are impulse center instant and impulse amplitude. Algorithms are also provided for computing fluctuation of level parameters and certain types of jitter.

IV. Examples

The proposed standard contains several other example waveforms like fig. 1 (which shows a pulse waveform and its corresponding parameters). In addition to this type of waveform example, the proposed standard includes several reference waveforms and their corresponding analytical forms. These are called reference waveforms because they can be reproduced exactly and are often used as a reference in calculating waveform aberrations. Waveform aberrations are computed by doing a point-by-point subtraction of a reference waveform from the measured waveforms. Examples of some of the reference waveforms given in the proposed standard are a step waveform:

$$W_{step}(t) = \begin{cases} 0 & t < t_1 \\ a & t \geq t_1 \end{cases},$$

where a is the waveform amplitude; and an exponential waveform:

$$W_{\exp}(t) = \begin{cases} 0 & t < t_1 \\ a\left[1 - e^{-(t-t_1)/b}\right] & t \geq t_1 \end{cases},$$

where b is the exponential time constant. Figures are also provided for these reference waveforms. Compound waveform examples, such as a double pulse, a bipolar pulse, a staircase, and a pulse train are also provided. These waveforms can also be used as a basis for comparison and discussion.

V. Summary

The SCOPT has completed a major revision of the expired IEEE standards on pulse techniques and definitions. The major improvement in the proposed standards has been in the clarification and updating of the definitions section and the addition of algorithms for extracting waveform parameters.

References

1. IEEE Standard on Pulse Measurement and Analysis by Objective Techniques, STD-181-1977, Institute of Electrical and Electronic Engineers, 445 Hoes Lane, Piscataway, NJ 08855.
2. IEEE Standard Pulse Terms and Definitions, STD-194-1977, Institute of Electrical and Electronic Engineers, 445 Hoes Lane, Piscataway, NJ 08855.
3. Pulse Techniques and Apparatus, Part 1: Pulse terms and definitions, IEC 60469-1, Second Edition, 1987.
4. Pulse Techniques and Apparatus, Part 2: Pulse measurement and analysis, general considerations, IEC 60469-2, Second Edition, 1987.
5. IEEE Subcommittee on Pulse Techniques, http://grouper.ieee.org/groups/181/index.html